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ABSTRACT

This Monte Carlo study explored relationships among standard and unstandardized regression coefficients, structural coefficients, multiple R_ squared, and significance level of predictors for a variety of linear regression scenarios. Ten regression models with three predictors were included, and four conditions were varied that were expected to have influences on the relationship under investigation: (1) magnitude of direct effect from predictors to the outcome variable; (2) colinearity; (3) sample sizes; and (4) model misspecification. Results show that regression parameter estimates behave differently under influences of strength of direct effect of predictors, sample size, and collinearity conditions. Although all the parameter estimates are sensitive to variations of strengths of predictors' effects, some parameter estimates are vulnerable to variations of sample size and collinearity conditions. Standard regression coefficients Beta exhibit the best performance under these specific conditions. Structural coefficients, on the other hand, show relatively less sensitivity to variations of strength of direct effect of predictors, and are very vulnerable to collinearity conditions. R_Squared issensitive to strength of direct effect of predictors; it is vulnerable somewhat to collinearity conditions. Significance level of predictors is most sensitive to variations of strength of direct effect of predictors than structural coefficients; meanwhile, it is largely vulnerable to sample size and somewhat vulnerable to collinearity conditions. One appendix contains 10 models, and the other contains the study tables. (Contains 10 figures (models), 17 tables, and 6 references.) (Author/SLD)

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Understanding and Interpreting Regression Parameter Estimates in Given Contexts: A Monte Carlo Study of Characteristics of Regression and Structual Coefficients, Effect Size R Squared and Significance Level of Predictors

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Abstract

Regression analysis is a common statistical approach adopted by many quantitative researchers in social science. It is a method of analyzing the variability of a dependent variable by resorting to information available or a dependent variable or a set of independent variables (Pedhazur, 1997). In regression framework, common approaches to hypothesis testing include test of multiple R_squared, regression coefficients, and relative importance of variables, etc. Courville and Thompson (2001) found regression researchers too infrequently consult regression structural coefficients to augment their interpretation. According to Courville and Thompson, reliance on reporting only standard regression coefficients, Betas, may not be sufficient to help understand findings for certain types of applied research.

Although there is a large body of literature on existing regression theories and applications, studies on characteristics of regression parameter estimates using simulated empirical data are limited. Hence, little is known how these regression parameters perform under influences of different factors. This Monte Carlo study explores relationships among standard and unstandardized regression coefficients, structural coefficients, multiple R_squared, and significance level of predictors for a variety of linear regression scenarios. Ten regression models with three predictors are included in the study. Four conditions are varied that are expected to have influences on the relationship under investigation, namely (1) Magnitude of direct effect from predictors to the outcome variable; (2) Collinearity; (3) Sample Sizes; (4) Model Misspecification.

Results show that regression parameter estimates behave differently under influences of strength of direct effect of predictors, sample size and collinearity conditions. Although all the parameter estimates are sensitive to variations of strengths of predictors' effects, some parameter estimates are vulnerable to variations of sample size and collinearity conditions. Standard regression coefficients Beta exhibit the best performance under these specific conditions. Structural coefficients on the other hand show relatively less sensitivity to variations of strength of direct effect of predictors, and are very vulnerable to collinearity conditions. R_Squared is sensitive to strength of direct effect of predictors; it is vulnerable somewhat to collinearity conditions. Significance level of predictors is more sensitive to variations of strength of direct effect of predictors than structural coefficients; meanwhile, it is largely vulnerable to sample size and somehow vulnerable to collinearity conditions.

Introduction

Regression analysis is a common statistical approach adopted by many quantitative researchers in the field of social science. It is a method of analyzing the variability of a dependent variable by resorting to information available on an independent variable or a set of independent variables (Pedhazur, 1997). The overall inferential test in multiple regression is whether the sample of scores is drawn from a population in which the multiple R is zero. This is equivalent to the null hypothesis that all correlations between predictors and outcome variable and all the regression coefficients are zero (Tabachnic and Fidel, 2000).

In regression framework, common approaches to hypothesis testing include test of R_squared, regression coefficients, and relative importance of variables.

a) Test of R_Squared

R_Squared indicates the proportion of variance of the dependent variable accounted for by the independent variable(s). Also, 1- R_Squared is the proportion of the dependent variable not accounted for by the independent variable(s) or the error variance. The significance of R_Squared is tested as

$$F = \frac{R_Squared / k}{(1 - R_Squared) / (N-k-1)}$$

where k is the number of independent variables. The same F ratio is obtained from the ratio of MSreg to MSres in the regression variance summary (Pedhazur, 1997).

b) Test of Regression Coefficients

Each regression coefficient (b) in a multiple regression indicates the expected change in Y associated with a unit change in the independent variable under consideration while controlling for, or holding constant, the effects of the other independent variables. Dividing a b by its standard error yields a t ratio. T-tests are used to test whether the obtained b differs significantly from zero or some other hypothesized parameter.

c) Test of R_Squared versus Test of b

As Pedhazur (1997) notes, the test of R_Squared is tantamount to testing all the b's simultaneously. When testing a given b for significance, the question addressed is whether it differs from zero while controlling for the effects of the other independent variables. The two tests address different questions. Further, failure to distinguish between the purposes of the two tests has led some researchers to maintain that they might lead to contradictory or puzzling conclusions.

d) Relative Importance of Variables

Researchers use diverse approaches aimed at determining the relative importance of the independent variables under study. The magnitude of b is affected by the scale of measurement used to measure the variable with which the b is associated and thus is not an ideal comparative

criteria. Because the incomparability of b's, researchers often resort to comparisons among standardized regression coefficients (Beta), as they are based on standard scores. As cautioned by Pedhazur (1997), interpretation using Beta's is legitimate but not free of problems because Beta's are affected by the variability of the variables with which they are associated.

Purpose

Courville and Thompson (2001) found regression researchers too infrequently consult regression structural coefficients to augment their interpretation. According to Courville and Thompson, reliance on reporting only standard regression coefficients, Betas, may not be sufficient to help understand findings for certain types of applied research. They further suggested that interpreting structural coefficients along with standardized regression coefficients would be more helpful to gain insight of research findings.

Contrary to Courville and Thompson's claims, Pedhazur (1997) has shown that structural coefficients are simply zero-order correlations of independent variables with dependent variables divided by a constant, namely, the multiple correlation coefficient. Hence, the zero order correlations provide the same information.

Further, as the newest edition of APA (2001) manual requires authors to report findings using values reflect magnitude of effect size and strength of relationship along with statistical significance. In regression framework, although there is a large body of literature on existing regression theories and applications, the studies of regression parameters estimates characteristics using simulated empirical data are limited. Hence, little is known how these regression parameters perform under influences of different factors.

This Monte Carlo study explores the relationships among standardized and unstandardized regression coefficients, structural coefficients, multiple R-squared and significance level of predictors for a variety of linear regression scenarios. Further, the study investigates the relationship among significance level of predictors, standardized and unstandardized regression coefficients, structural coefficients and multiple R-squared and its F-Test. The study includes ten regression models, each with three predictors.

Methods

Models Included:

The simulation study includes 10 models (See Appendix A). Four conditions are varied that are expected to have influences on the relationship under investigation, namely (1) Magnitude of direct effect from predictors to the outcome variable; (2) Collinearity; (3) Sample Sizes, and (4) Model Misspecification.

1) Control of magnitude of direct effect:

In models 1 and 6, the direct effects of predictors on the outcome variable are weak, and are fixed at .15. In models 2 and 7, the direct effects of predictors are a little stronger, and are fixed at .25. In models 3 and 8, the direct effects of predictors are even stronger, and are fixed at .35. In models 4 and 9, the direct effects of predictors are strong, and are fixed at .50.

In Models 5 and 10, the direct effects of the predictors vary. One predictor has weak effect (.15), the second predictor has medium effect (.35) and the third predictor has strong effect (.50) upon the outcome variable.

2) Control of collinearity:

In each model, there are 3 predictor variables and 1 outcome variable. In model 1 to 5, the inter-correlations shared by the three predictors are .35. In models 6 to 10, the inter-correlations shared by the three predictors are .80.

3) Control of sample size:

Three sample sizes are applied to each of the 10 models. The three sample sizes are 200, 500, and 1,000.

4) Control of Model Misspecification:

For models 5 and 10 where there are predictors of different strengths, namely .15, .25 and .50 in one same model, regression parameters are estimated when we intentionally overlook one of the predictors of different strength. The purpose is to examine the effect of excluding a relevant variable of different strength on magnitude of the regression parameter estimates. There are 4 levels of misspecification: a) all the relevant predictors are included; b) the weakest predictor (.15) is excluded; c) a stronger predictor (.25) is excluded; and d) the strongest predictor (.50) is excluded.

Procedure

EQS (Bentler and Wu, 1995) is used to simulate the data. There are 10 different models each with 3 different sample sizes. Each model is replicated 400 times. A total of 12,000 raw data conditions are replicated. SPSS is used to analyze the resulting parameter estimates.

Data Analysis

After the raw data files have been created, we use SPSS to perform analyses to write out regression parameter estimates and correlations matrices. These data are saved to an out file to be further analyzed. Descriptive statistics such as means, medians and standard deviations of parameter estimates are reported. Eta squared obtained using analysis of variance (ANOVA) procedures are used to describe the variance accounted for by factors influencing the magnitude of parameter estimates. Eta squared can be interpreted as the proportion of the total variability in the dependent variable that is accounted for by variation in the independent variable. It is the ratio of the between groups sum of squares to the total sum of squares. According to Cohen (1988), an eta squared = .01 is considered small effect size, an eta squared =.09 a medium effect size, and an eta squared = .25 a large effect size.

Characteristics of standardized regression coefficients (beta weights):

Standardized regression coefficients seem to vary according to different models included. Magnitudes of standardized regression coefficients increase as the strength of predictors increase. The eta squared associated with the strength of predictors is .940. Standardized regression coefficients stay relatively stable as the sample sizes increase. The eta squared associated with sample size is .00004. Further, standardized regression coefficients don't seem to be sensitive to collinearity conditions. The eta squared associated with collinearity conditions is only .003. Standardized regression coefficients vary under different conditions of misspecification. When a weak predictor is excluded from the model, magnitudes of standardized regression coefficients of other predictors tend to increase. When a stronger predictor is overlooked, magnitudes of standardized regression coefficients of other predictors tend to decrease. The eta squared associated with the degree of misspecification is .879.

Characteristics of structural regression coefficients:

Structural regression coefficients (the zero order correlations between predictors and the outcome variable divided by multiple R) seem to vary according to different models included and conditions of collinearity. Structural coefficients increase very slightly as strength of predictors increase. The eta squared associated with the strength of predictors is .023. They stay relatively stable as sample size increases. The eta squared associated with sample size is .012. Collinearity

conditions appear to have significant influence on magnitude of the structural coefficients. The eta squared associated with collinearity conditions is .726. Structural regression coefficients vary under misspecification conditions. It appears structural regression coefficients increase in magnitude when a stronger predictor is excluded from the model. The eta squared associated with misspecification conditions is .796.

Characteristics of t ratios:

T-ratios (raw standardized regression coefficients divided by their corresponding standard errors) vary according to different models included. Magnitudes of T-ratios increase as the strength of the predictors increase. The eta squared associated with the strength of the predictors is .534. T-ratios increase as sample size increases. The eta squared associated with sample size is .318. T-ratios vary less significantly with collinearity conditions. The eta squared associated with collinearity conditions is .056. Conditions of misspecification seem to influence T-ratios. T-ratios decrease as the strength of an excluded predictor increases. The eta squared associated with misspecification conditions is .505.

Characteristics of significance level of unstandardized regression coefficients:

Significance level (p value) of unstandardized regression coefficients seems to vary according to different models included, sample sizes, and conditions of collinearity. The average significance level of the three predictors decreases as the strength of predictors increases. The eta squared associated with the strength of predictors is .249. The average significance level of three predictors also decreases as sample sizes increase. The eta squared associated with sample sizes is .131. The average significance level of the three predictors increases slightly as the inter-correlations among the three predictors increase. The eta squared associated collinearity conditions is .034. Significance level of unstandardized regression coefficients increases as the strength of an excluded predictor increases. The eta squared associated with misspecification conditions is .195.

Characteristics of R_Squared

Effect sizes of regression models measured by model R_Squared vary significantly according to different models included. The eta squared is .936. The R_Squared decrease very slightly as sample sizes increase. The eta squared associated with sample sizes is .003. The R_Squared squared increase slightly as the inter-correlations among the predicators increase. The eta squared associated with collinearity conditions is .014. Model R_Squared vary significantly under misspecification conditions. R_squared decreases as the strength of an excluded predictor increases. The eta squared associated with conditions of misspecification is .784.

Results and Discussions

Under influence of strength of direct effect of predictors:

It is encouraging to see that all the parameters of regression analysis under study are sensitive to different models. In other words, these parameters are sensitive to variation of strength of direct effect of predictors. Both standard regression coefficients Beta and R_Squared vary systematically according to the magnitude of direct effect of predictors. The amount of variance explained amount to above 90%. Structural coefficients show slight increase as the direct effect of predictors increase. The amount of variance explained is a little over 2%.

Significance level of predictors resulted from t-tests decreases as the strength of predictors increases, the amount of variance explained is 20%.

Under influence of sample size:

R_Squared, standard regression coefficients and structural coefficients are stable under influence of sample size. The amount of variance accounted for by sample size is around or less than 1%. Among all the parameters under investigation, standardized regression coefficients remain very stable due to influence of sample size. On the other hand, significance level of predictors resulted from t-tests is influenced by sample size. Significance level decreases as sample size increases. The amount of variance in significance level explained by sample size is about 13%. T-ratios are also influenced by sample size. The amount of variance accounted for sample size in T-ratios amount to 32%.

Under influence of collinearity conditions:

Standardized coefficients Beta remain very stable under the influence of collinearity conditions. The amount of variance explained is far less than 1%. R_Squared vary slightly under the influence of collinearity conditions. The amount of variance explained is about 1.4%. There is about 3% of variance in significance level of predictors that can be accounted for by the collinearity conditions. The p value increases slightly as the inter-correlations among the predictors increase. Structural coefficients are very significantly influenced by collinearity conditions. About 73% of variance in the structural coefficients can be explained by collinearity conditions. As the inter-correlations among the predictors increase, the magnitude of structural coefficients increases.

Under influence of misspecification conditions:

As expected, magnitudes of standardized regression coefficients of included predictors decrease as stronger predictors are excluded from the model. The amount of variance explained is 88%. However, magnitudes of structural coefficients of included predictors included increase as the stronger predictors are excluded from the model. In other words, the exclusion of some more important variables seems to inflate the importance of less important variables in the model. The variance associated with exclusion of stronger variables is about 80%. T-ratios decrease their magnitudes as stronger predictors are excluded from the model. The variance explained is about 51%. Finally, R_squared decreases as the strength of an excluded variable increases. The variance accounted for is 78%.

Implications

This study provides empirical data to study the characteristics of regression parameters. It is found that not all the parameters behave in a same way under influences. Researchers need to be aware of the unique characteristics of the parameters in certain contexts.

The results show that regression parameter estimates behave differently under influences of strength of direct effect of predictors, sample size and collinearity conditions. Although all the parameter estimates are sensitive to variations of strengths of predictors' effects, some parameter estimates are vulnerable to variations of sample size and collinearity conditions. Standard regression coefficients Beta exhibit the best performance under these specific conditions. Structural coefficients on the other hand show relatively less sensitivity to variations of strength of direct effect of predictors, and are very vulnerable to collinearity conditions. R_Squared is sensitive to strength of direct effect of predictors; it is vulnerable somewhat to collinearity

conditions. Significance level of predictors is more sensitive to variations of strength of direct effect of predictors than structural coefficients; meanwhile, it is largely vulnerable to sample size and somehow vulnerable to collinearity conditions.

Researchers using regression methods should consider influential factors such as sample size and collinearity conditions where the study is carried out, given the different performance patterns the regression parameter estimates exhibited under the influences. To conclude, although regression analysis is a useful tool in social science research, there is a need to understand and interpret regression parameters wholistically.

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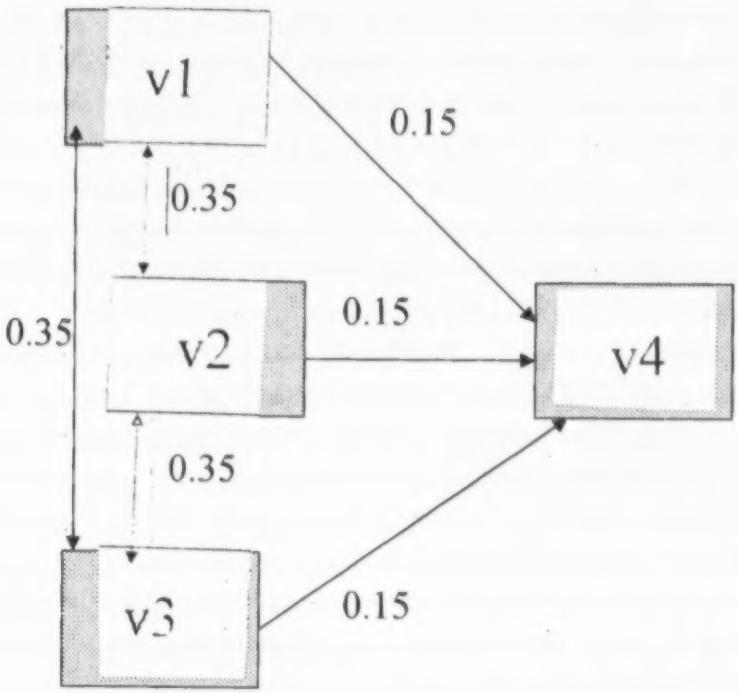
APPENDIX A

Model 1



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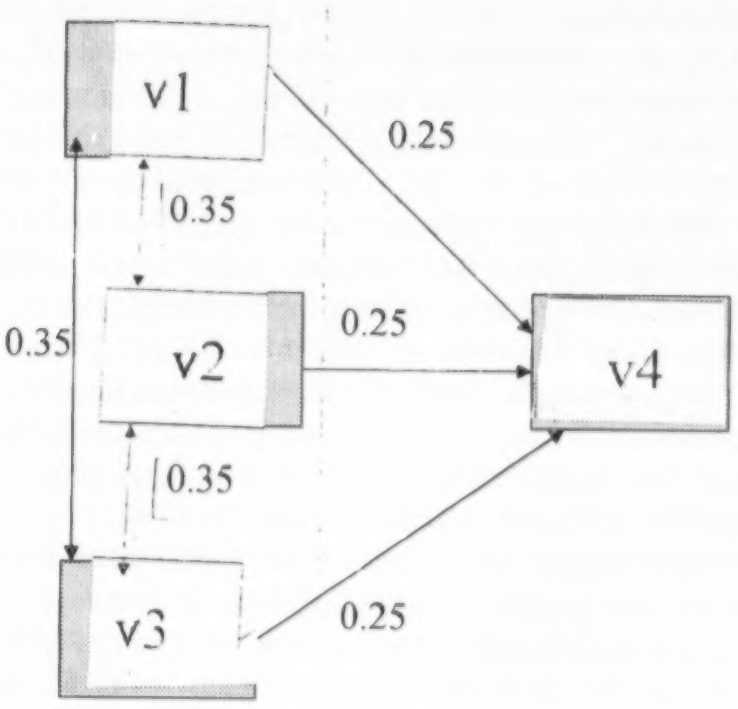
Model 2



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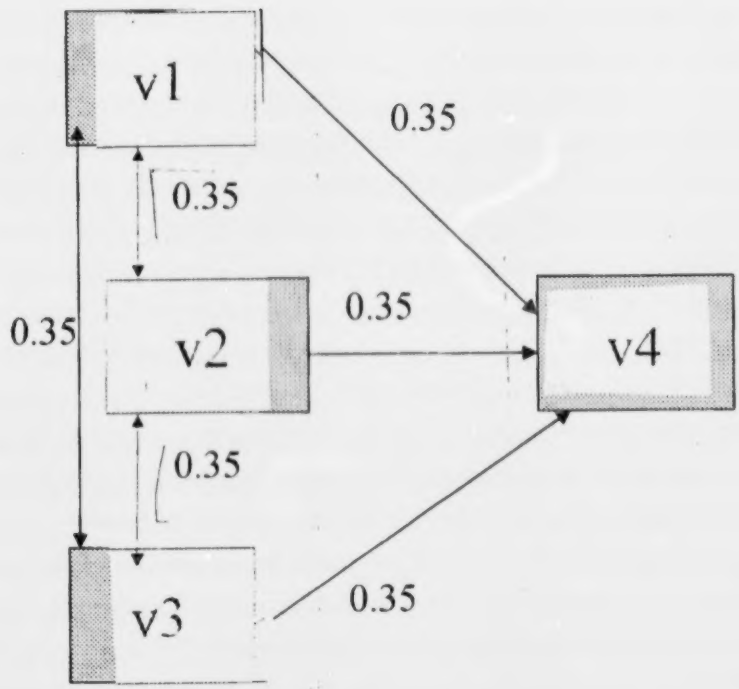

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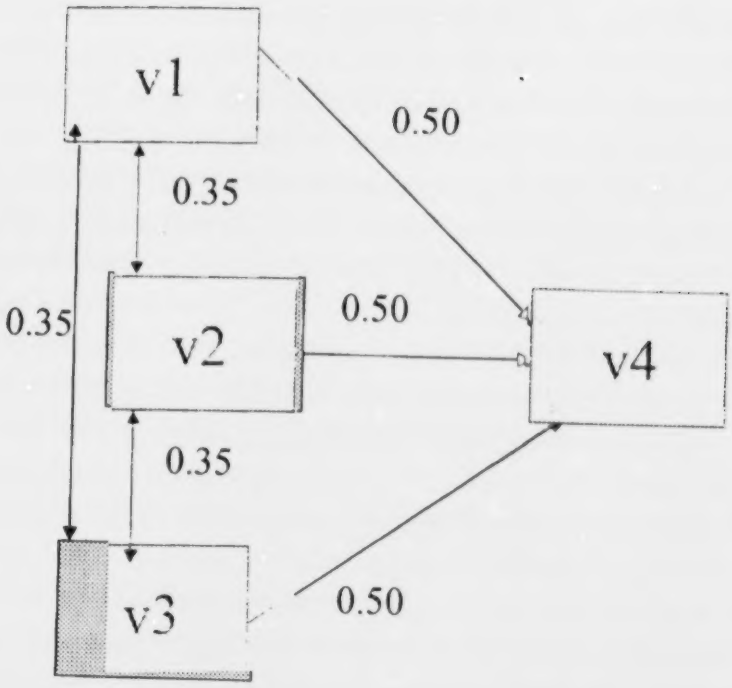

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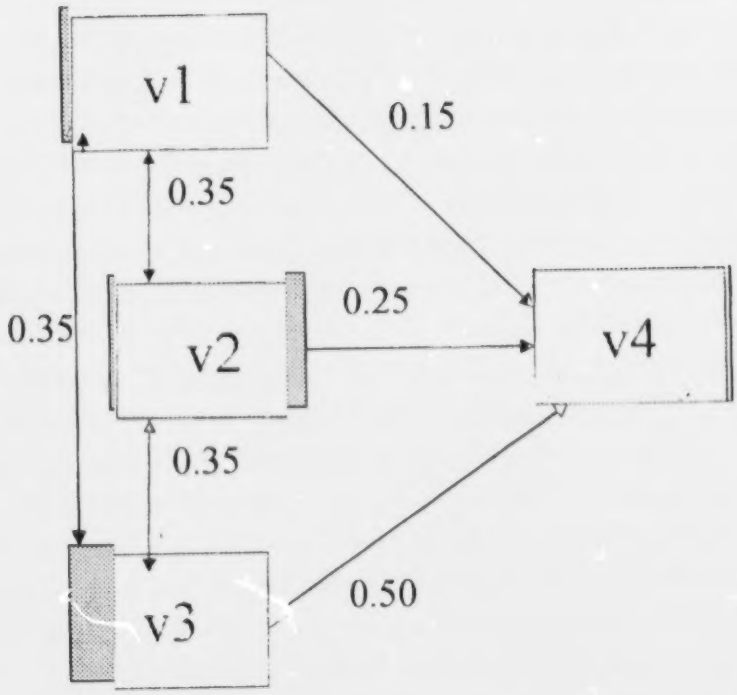

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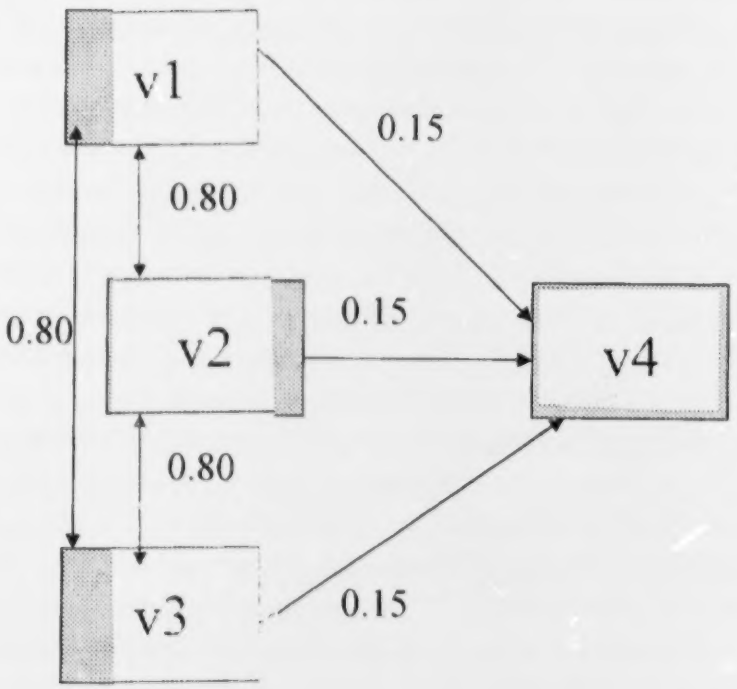

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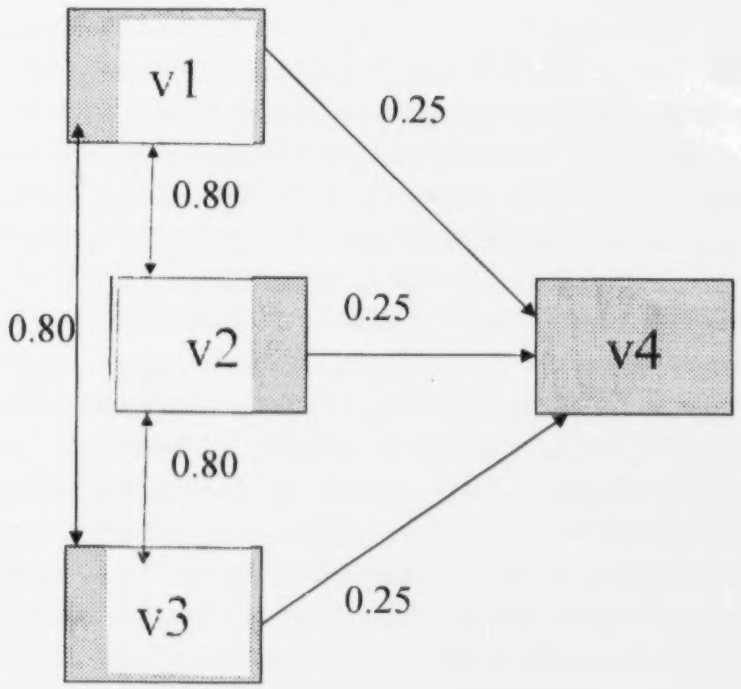

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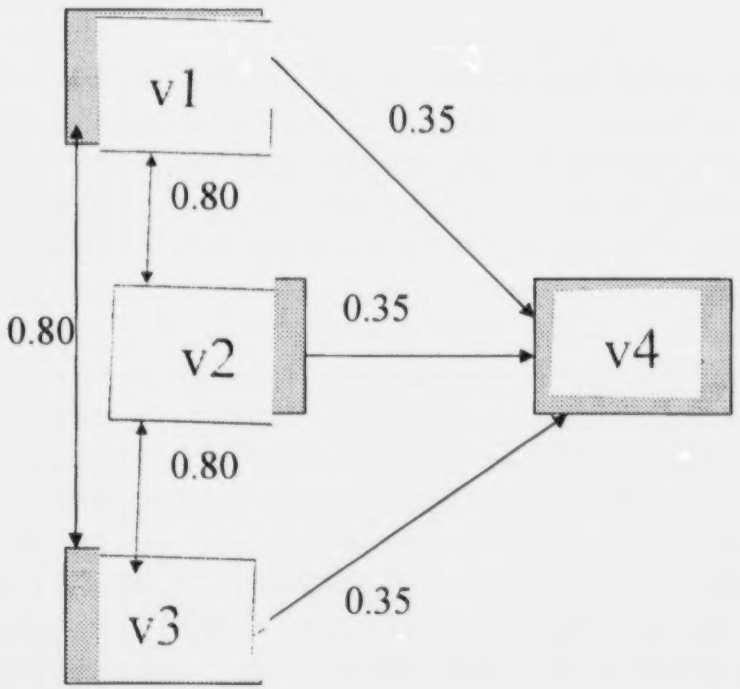

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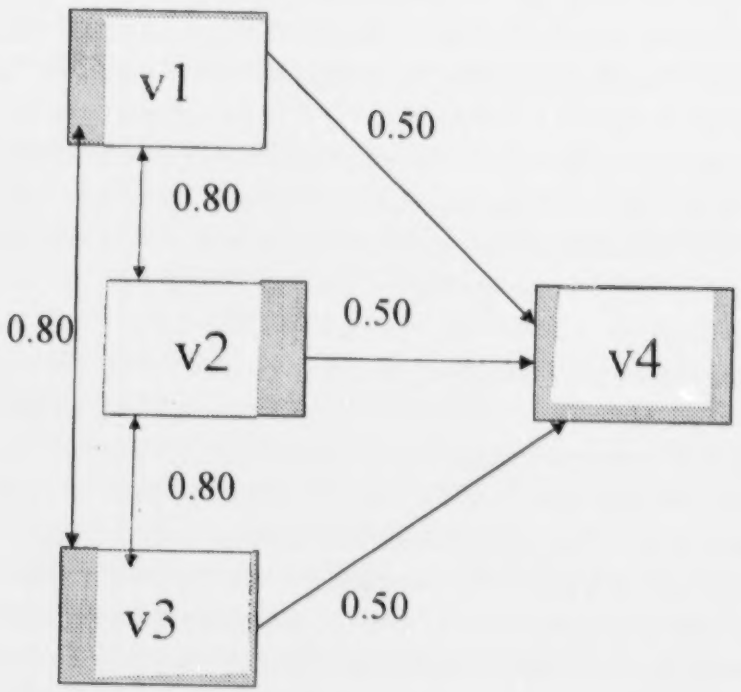

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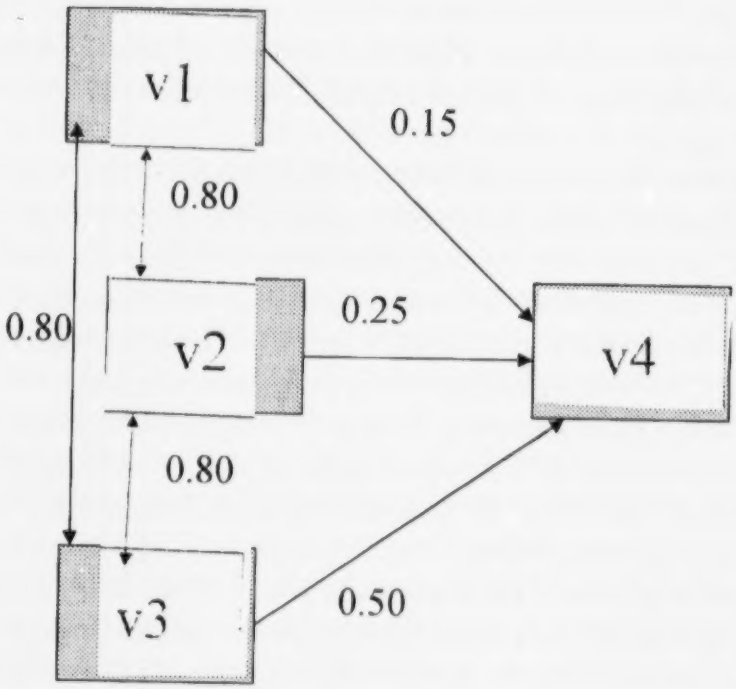
Model 10



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APPENDIX B

Table 1: Significance level of the three predictors V1, V2, and V3 by strength of predictors

Strength of Predictors	Models	Mean	N	Std. Deviation	Median	Effect Size (Eta Squared)
.15	1, 6	.0897	2400	.113	.034	
.25	2, 7	.0192	2400	.047	.000	
.35	3, 8	.0042	2400	.018	.000	**.249**
.50	4, 9	.0003	2400	.003	.000	
Total		.0282	9600	.072	.000	

Table 2: Significance level of the three predictors V1, V2 and V3 by sample sizes

Sample Size	Mean	N	Std. Deviation	Median	Effect Size (Eta Squared)
200	.064	3200	.104	.007	
500	.017	3200	.047	.000	**.131**
1000	.003	3200	.018	.000	
Total	.028	9600	.072	.000	

Table 3: Significance level of three predictors V1, V2, and V3 by collinearity conditions

Collinearity Condition	Mean	N	Std. Deviation	Median	Effect Size (Eta Squared)
.35	.0149	4800	.0513	.0000	
.80	.0414	4800	.0852	.0010	**.034**
Total	.0282	9600	.0716	.0000	

Table 4: Standardized regression coefficients by strength of predictors

Strength of predictors	Models	Mean	N	Std. Deviation	Median	Effect Size (Eta Squared)
.15	1, 6	.1446	2400	.0233	.1447	
.25	2, 7	.2238	2400	.0201	.2238	
.35	3, 8	.2858	2400	.0182	.2854	**.940**
.50	4, 9	.3512	2400	.0031	.3501	
Total		.2513	9600	.0787	.2583	

Table 5: Standardized regression coefficients by sample size

Sample Size	Mean	N	Std. Deviation	Median	Effect Size (Eta Squared)
200	.2501	3200	.0807	.2582	
500	.2510	3200	.0782	.2582	**.00004**
1000	.2520	3200	.0773	.2598	
Total	.2513	9600	.0787	.2583	

Table 6: Standardized regression coefficients by collinearity condition

Collinearity Condition	Mean	N	Std. Deviation	Median	Effect Size (Eta Squared)
.35	.2559	4800	.0819	.2632	
.80	.2468	4800	.0751	.2545	**.003**
Total	.2513	9600	.0787	.2583	

Table 7: Structural regression coefficients by strength of predictors

Strength of predictors	Models	Mean	N	Std. Deviation	Median	Effect Size (Eta Squared)
.15	1, 6	.6596	2400	.0496	.6539	
.25	2, 7	.6714	2400	.0414	.6693	
.35	3, 8	.6747	2400	.0405	.6744	**.023**
.50	4, 9	.6764	2400	.0402	.6780	
Total		.6705	9600	.0436	.6668	

Table 8: Structural regression coefficients by sample size

Sample Size	Mean	N	Std. Deviation	Median	Effect Size (Eta Squared)
200	.6641	3200	.0501	.6663	
500	.6724	3200	.0406	.6668	**.012**
1000	.6751	3200	.0385	.6724	
Total	.6705	9600	.0436	.6668	

Table 9: Structural regression coefficients by collinearity condition

Collinearity Condition	Mean	N	Std. Deviation	Median	Effect Size (Eta Squared)
.35	.6333	4800	.0243	.6363	
.80	.7077	4800	.0212	.7104	**.726**
Total	.6705	9600	.0436	.6668	

Table 10: Average T-ratios by strength of predictors

Strength of predictors	Models	Mean	N	Std. Deviation	Median	Effect Size (Eta Squared)
.15	1, 6	2.905	2400	1.1089	2.825	
.25	2, 7	4.822	2400	1.7395	4.674	**.534**
.35	3, 8	6.739	2400	2.3891	6.539	
.50	4, 9	9.615	2400	3.3751	9.415	
Total		6.021	9600	3.3884	5.289	

Table 11: T-ratios by sample size

Sample Size	Mean	N	Std. Deviation	Median	Effect Size (Eta Squared)
200	3.735	3200	1.7081	3.503	
500	5.914	3200	2.6308	5.544	**.318**
1000	8.413	3200	3.6984	7.916	
Total	6.021	9600	3.3884	5.289	

Table 12: T-ratios by collinearity condition

Collinearity Condition	Mean	N	Std. Deviation	Median	Effect Size (Eta Squared)
.35	6.820	4800	3.6968	6.038	.056
.80	5.221	4800	2.8321	4.598	
Total	6.021	9600	3.3884	5.289	

Table 13: Effect size model R^2 by strength of predictors

Strength of predictors	Models	Mean	N	Std. Deviation	Median	Effect Size (Eta Squared)
.15	1, 6	.094	2400	.029	.090	.936
.25	2, 7	.213	2400	.041	.210	
.35	3, 8	.342	2400	.046	.341	
.50	4, 9	.512	2400	.045	.513	
Total		.290	9600	.161	.277	

Table 14: Effect size model R^2 by sample size

Sample Size	Mean	N	Std. Deviation	Median	Effect Size (Eta Squared)
200	.2944	3200	.1628	.2807	.003
500	.2885	3200	.1600	.2738	
1000	.2880	3200	.1509	.2733	
Total	.2903	9600	.1607	.2767	

Table 15: Effect size model R^2 by collinearity condition

Collinearity Condition	Mean	N	Std. Deviation	Median	Effect Size (Eta Squared)
.35	.2712	4800	.1529	.2604	.014
.80	.3094	4800	.1660	.3016	
Total	.2903	9600	.1607	.2767	

Table 16: Significance level of predictors by excluding a relevant predictor

Strength of an Excluded Predictor	Models	Mean	N	Std. Deviation	Median	Effect Size (Eta Squared)
0	5, 10	.04525	2400	.07323	.00846	.195
.15		.00002	2400	.00206	.00000	
.25		.00018	2400	.01623	.00000	
.50		.08687	2400	.12438	.02453	
Total		.03353	9600	.02453	.00005	

Table 17: Standardized regression coefficients of predictors by excluding a relevant predictor

Strength of an Excluded Predictor	Models	Mean	N	Std. Deviation	Median	Effect Size (Eta Squared)
0	5, 10	.25649	2400	.01827	.25629	.879
.15		.35725	2400	.02838	.35753	
.25		.33941	2400	.03470	.34002	
.50		.17129	2400	.02580	.17191	
Total		.28111	9600	.07885	.28487	

Table 18: Structural regression coefficients of predictors by excluding a relevant predictor

Strength of an Excluded Predictor	Models	Mean	N	Std. Deviation	Median	Effect Size (Eta Squared)
0	5, 10	.60804	2400	.04720	.60826	.796
.15		.69093	2400	.02387	.69251	
.25		.67826	2400	.02982	.68195	
.50		.86652	2400	.07497	.84631	
Total		.71094	9600	.10674	.68843	

Table 19: Average T-ratios of predictors by excluding a relevant predictor

Strength of an Excluded Predictor	Models	Mean	N	Std. Deviation	Median	Effect Size (Eta Squared)
0	5, 10	6.13581	2400	2.08047	5.95300	.505
.15		9.47645	2400	3.12964	9.26153	
.25		8.90396	2400	3.01512	8.74083	
.50		3.13562	2400	1.30464	2.99592	
Total		6.91296	9600	3.54678	6.18134	

Table 20: Effect size model R^2 by excluding a relevant predictor

Strength of an Excluded Predictor	Models	Mean	N	Std. Deviation	Median	Effect Size (Eta Squared)
0	5, 10	.28138	2400	.03968	.28070	.784
.15		.26937	2400	.04063	.26828	
.25		.25125	2400	.04323	.25016	
.50		.09826	2400	.03042	.09604	
Total		.22506	9600	.08355	.25052	

(Significance Level of Predictors)

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